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August 1, 2018

Statement of

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before the
Subcommittee on Space, Science, and Competitiveness
Committee on Commerce, Science, and Transportation
United States Senate

Chairman Cruz, Senator Markey and Members of the Committee, I am pleased to have the opportunity to appear before you today to discuss the search for life beyond Earth. As my esteemed colleagues Dr. Seager and Dr. Spergel will focus on life beyond our Solar System, and the importance of missions like the James Webb Space Telescope and the Giant Magellan Telescope for keeping the United States at the forefront of deep space discovery, I will focus on the search for life within our Solar System.

As a planetary scientist, the former Chief Scientist of NASA and the current John and Adrienne Mars Director of the Smithsonian's National Air and Space Museum, there is no topic that I find so exciting, or so fundamental and profound for future discoveries that will one day be highlighted in my museum, as this one.

As with everything in planetary science, the discussion has to start here, on Earth, the planet we know and love best. Life, based on our understanding of how it arose here, requires water, liquid water, that has been stable on the surface of a planet for a very long time.

Life on Earth evolved rapidly once conditions stabilized, with chemical signatures indicative of life detected in rocks that date to 3.8 billion years ago. At that point, Earth was an ocean planet, and life would remain in the ocean, and in relatively simple forms, for over one billion years.

The study of life on Earth is key to the search for life elsewhere. To date, we have learned that it is tough, tenacious, metabolically diverse, and highly adaptable to local environmental conditions. Astrobiologists have found life in extreme terrestrial environments, from volcanic lakes to glaciers to sulfur springs- even at the very top of the stratosphere. Microbes have been found that live under high levels of radiation, as well as bacteria that consume chemicals that would be toxic to most other life.

So how does this inform our search for life elsewhere in the solar system? It makes us optimistic. We know that the building blocks of life, amino acids, are ubiquitous in the solar system, found in comets, asteroids and even interstellar clouds. Taken with the fact that life arose so quickly here, given the right building blocks and stable conditions, it is highly unlikely that life is unique to our planet. And so, based on our one data point, life on Earth, we head outward into the solar system to search.

The first step is to identify environments potentially habitable to microbial life— with conditions similar to those on the early Earth— liquid water, a source of nutrients, and a source of energy. To date, we have identified three highly likely targets, and one outlier, that I will come back to at the end of my remarks.

When we look for planets that could harbor life around other stars, we look in the habitable zone— a band of space at the right distance from the star, where liquid water might be stable on the surface of the exoplanet. But here in this solar system, we find possible targets for life well beyond the habitable zone, within the icy moons of the outer planets. I say *within*, because spacecraft to the outer solar system have found subsurface water oceans beneath the icy crusts of Jupiter's moon Europa and Saturn's moon Enceladus.

These subsurface, liquid-water oceans have likely persisted for over one billion years, and are likely enriched by volcanic eruptions from their inner rocky cores, providing stability, and possible sources of nutrients and energy. Both Enceladus and Europa vent their oceans out to space in geyser-like eruptions, allowing for potentially easy sampling to search for life. Cassini sampled the liquid erupting from Enceladus, determining that it was water, along with salts, silica, and organic molecules- all pointing to a habitable environment. But Cassini's instruments weren't designed to find life, so we need to go back, with better instruments.

Future missions to these bodies are being developed or studied. An important question that the astrobiology community has been working on is- will we know life when we see it? How Earth-like will it be? To help sort out the scientific possibilities, astrobiologists have worked on something called the ladder of life, which lays out what to measure and how to measure it, from the first rung of understanding whether an environment is habitable, to higher rungs searching for biomolecules, then metabolism, to the ultimate identifier of Darwinian evolution.

The astrobiology community has a well-thought out, peer-reviewed approach that would not have been possible without years of basic research, from theoretical work, to research in the lab and in the field, to get us this far in our understanding of where and how to search for life beyond Earth.

It took a series of NASA spacecraft missions, starting with Voyager and Galileo to the Jovian system and Cassini-Huygens to the Saturnian system, to get us to the point where we know to take the next steps of exploration at Europa and Enceladus, two of the three likely candidates for life elsewhere in the solar system. The third, of course, is Mars.

About 3.8 billion years ago, a significant portion of the surface of Mars was covered in water. Mars remained wet for at least 500 million years, before it lost its magnetic field, its atmosphere thinned, and conditions became similar to those we see today, with a cold, dusty, dry surface bombarded by solar and cosmic radiation. This detailed history of Mars has been made possible by decades of spacecraft flying by, orbiting, landing, and roving on the surface of the Red Planet, from the earliest Mariner data, to the Viking images that allowed us to study the great dry riverbeds, to the latest chemical measurements from Curiosity.

Understanding if life evolved on Mars during its relatively short, wet, early-Earth-like period, means searching on its rocky surface for fossilized microorganisms. That is why I feel strongly that astronauts—astrobiologists, geologists, and chemists—are required to do extensive fieldwork on the surface, not just to find evidence of past life on Mars, but to study multiple samples in order to understand its variation, complexity, and relationship to life on Earth.

NASA has assessed plans to get humans into Martian orbit by 2033, and down to the surface later in the decade, which is completely feasible and affordable if the agency focuses on the capabilities and technologies required.

A human to the Martian surface in 2038, a full twenty years from now, is far less audacious than the 'within the decade' call to get humans to the Moon that we will be celebrating in the coming year with the 50th anniversary of the Apollo missions. We have the infrastructure of NASA and its commercial partners, we have the scientific and technical knowledge, and the problem is extremely well-scoped and studied. We just need the will. Putting aside the amazing scientific and technological dividends, recall the incalculable benefit to this nation from the moonshots of the 1960s and 70s.

This is another extremely exciting moment in human history. We know where to look, and we know how to look. We have the technology to determine if life has evolved elsewhere in this solar system, and can easily do so within the next few decades.

Could there still be extant life on the Red Planet? In 2012, astrobiologists found that earth microbes can survive and grow in low pressure, freezing temperatures, and oxygen starved conditions seen on Mars. Microbes from permafrost soil gathered in Siberia grew at 7 millibars of atmospheric pressure, equivalent to Mars. And just last week, scientists using data from the US-Italian radar sounder on ESA's Mars Express spacecraft announced the discovery of a pool of liquid water beneath Mars' south polar layered terrain.

This is why planetary protection remains a critical area, to ensure that microbes from Earth do not contaminate our search for life and establish a presence on Mars ahead of us, but it also teases us with the scientific possibility that there is not just fossil life, but extant life to study beyond Earth.

I will return now to the outlier candidate I mentioned earlier. Most interesting to me is the possibility that life could exist in the absence of liquid water. That is one of the reasons why we study Titan, one of the moons of Saturn, where it rains liquid ethane and methane.

While the temperatures there are extremely cold and the seas and rivers flow with liquid hydrocarbons instead of H_2O, research indicates that membranes could form in such a liquid, an important step in cellular evolution. Future missions to Titan with its hydrocarbon seas, organic dunes and icy plains, will possibly provide a new insight into the question: What are the limits of life in our solar system—and beyond.

Thank you for the opportunity to testify today. I look forward to answering any questions you may have.